PB86-145463

Design Considerations for Ceramic Fine Bubble Grid Diffuser Systems

Houck (D.H.) Associates, Inc., Silver Spring, MD

Prepared for

Environmental Protection Agency, Cincinnati, OH

Jan 86

U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completir

1. REPORT NO.	2.	3. R PB86-145463
EPA/600/M-86/003		

4. TITLE AND SUBTITLE	5. REPORT DATE
Design Considerations for Ceramic Fine Bubbler Grid Diffuser Systems	January 1986
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Daniel H. Houck	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS D.H. Houck Assoc., Inc. Silver Spring, Maryland	10. PROGRAM ELEMENT NO.
	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Water Engineering Research Laboratory-Cincinnati, OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, OH 45268	13. TYPE OF REPORT AND PERIOD COVERED
	14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES
Project Officer: Frank Evans III, 513-569-7610
Water Engineering and Management, 104(7):R-8 thru R-13, July 31, 1985

16. ABSTRACT

Experience shows that dome or disk ceramic grid diffuser systems can be applied successfully and with major energy and operating cost savings in larger treatment plants treating primarily domestic wastes. The results of plant surveys in Europe and North America and the findings of extensive research on the design and operation of cermaic fine bubble dome and disk diffuser systems that are given here are useful for those concerned with designing or planning to acquire these systems.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
RELEASE TO PUBLIC	UNCLASSIFIED	8
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Water Engineering & Management, Reference Handbook 85, 104(7):R-8 thru R-13, July 31, 1985

Design Considerations for Ceramic Fine Bubble Grid Diffuser Systems

by Daniel H. Houck

The current generation of ceramic fine bubble diffuser equipment represents the culmination of nearly 20 years of development and experience in Europe. Presently, there are four major manufacturers of ceramic grid fine bubble diffusers. Numerous other manufacturers provide box, disk, and tube diffusers which use porous polystyrene diffusers. In recent years, as a result of major increases in energy costs, there has been renewed North American interest in efficient aeration equipment. The results of plant surveys in Europe and North America and the findings of extensive research on the design and operation of ceramic fine bubble dome and disk diffuser systems is useful for those concerned with designing or planning to acquire these systems.

Types of Ceramic Fine Bubble Diffusers

The original ceramic dome diffuser design, developed in the United Kingdom (U.K.), is a 7-in. ceramic dome manufactured by fusing alumina under conditions of high temperature and pressure. The dome is mounted on a support and piping network fabricated from unplasticized polyvinyl chloride piping. This configuration, shown in **Figure 1**, has been in use since 1970 with some modifications.

Several U.S. manufacturers have entered the market with ceramic disk diffusers claiming improved air dispersion over the horizontal area of the disk. Typical of this class of device is the disk diffuser shown in **Figure 2**. Disk diffusers measure about 9-in. diam and have a horizontal surface area that is larger than that of the 7-in. dome. Manufacturers claim that the larger surface area allows use of fewer disks than domes. This position is somewhat supported by studies[1] and comparative evaluations between domes and disks.[2] These types of diffusers are typically arranged in activated sludge aeration tanks as illustrated in **Figure 3**.

Previous and Current Research Efforts and Findings

Recent studies have shown that ceramic fine bubble dome/disk diffuser systems, while capable of consistently transferring oxygen at very high rates in clean water tests,[5] exhibit highly variable efficiencies under actual operating conditions in wastewater treatment plants. Plant surveys[3,4] indicate that many systems are transferring oxygen at rates much lower than expected. Current research projects are focusing on methods of optimizing design and operation of ceramic dome diffusers that improve performance by 75 percent compared to control units.[6] Other research includes methods of in-situ measurements of oxygen transfer by diffusers,[5] and the causes and remedies for ceramic dome diffuser fouling.[6,7]

Key observations from a survey of 26 municipal wastewater treatment plants with fine bubble diffusers located in the U.S. and Europe and from preliminary findings of other research projects, include the following:

—Ceramic dome/disk fine bubble diffusers exhibit wide variation in apparent oxygen transfer efficiency as estimated by mass balance computations.

—The most efficient plants average less than 500 scfm of air per lb of 5-*day biochemical oxygen demand* (BOD_5) applied; the least efficient require two to three times more air for the same BOD_5 removal.

—Plants receiving significant quantities of strong (high soluble BOD), highly degradable wastes from industries or from in-plant recycle streams tend to be less efficient than similar plants treating only domestic wastes.

—Most of the conventional secondary treatment plants with fine bubble diffusers experience some degree of biofouling. The most severe problems include causing coarse bubbling and loss of oxygen transfer efficiency.

—Generally plants using the single-stage nitrification process are more lightly loaded and less likely to experience diffuser fouling.

—Diffuser performance is also affected by the geometric configuration of the aeration tanks, arrangement of the diffusers on the tank floor, and tank inlet and outlet geometry.

—In general, plant operators trained in procedures for avoiding, diagnosing, or repairing ceramic grid diffuser system problems are likely to report good or excellent experience with the equipment.

Based on these studies, it appears that the primary determinants of ceramic grid dome/disk diffuser performance in activated sludge systems are:

—Process considerations: wastewater characteristics, process type, and loading conditions.

—Aeration tank design: tank geometry and inlet/outlet design.

—Aeration system: number of diffusers, diffuser distribution, mixed liquor dissolved oxygen control, and flexibility of air supply.

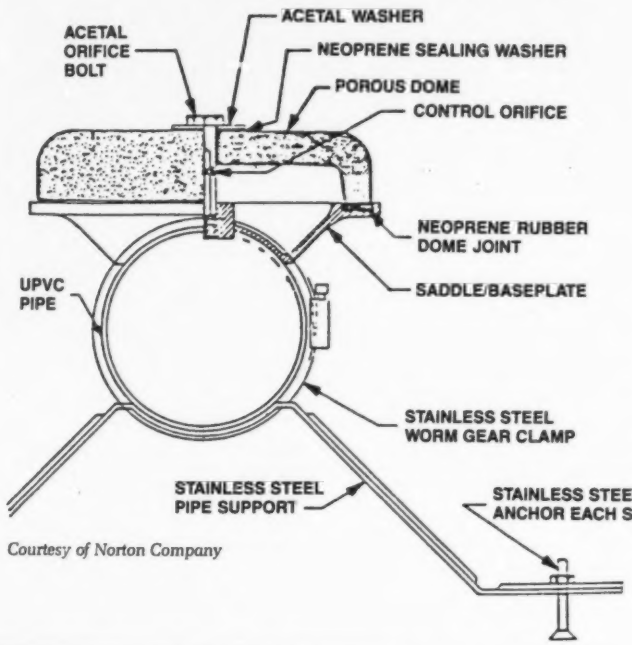
—Equipment and maintenance considerations: quality of hardware, system installation, operator training, and quality of preventive maintenance.

Process Considerations

The performance of fine bubble diffusers is measured by oxygen transfer efficiency. Process considerations that influence their performance include plant influent characteristics, treatment plant processes, and loading conditions. Very heavy sliming, leading to fouling of the diffusers and requiring frequent cleaning, was observed at treatment plants which receive wastes from milk solids processing, tanneries, corn syrup manufacture, rendering, pharmaceuticals, and recycle liquors from heat treatment processes. Bio-fouling at plants treating domestic wastes only appears related to process conditions, particularly a high *food-to-microorganism* (F/M) loading rate and low mixed liquor *dissolved oxygen* (DO). Nitrifying plants are much less likely to experience diffuser fouling than nonnitrifying plants. In general, the higher the plant F/M ratio and volumetric loading are, the lower the diffuser efficiency.

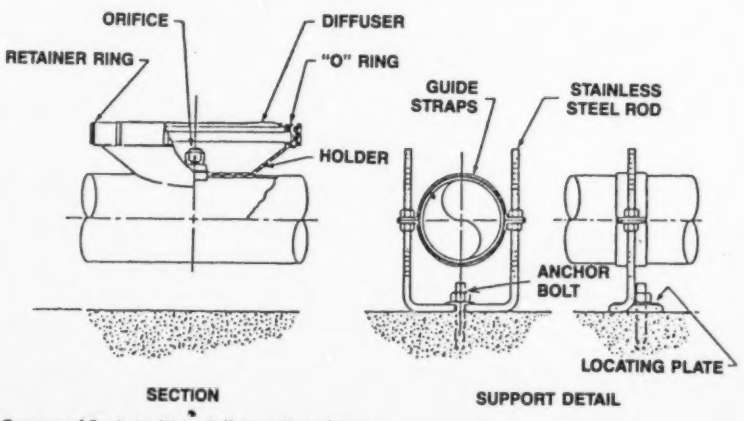
Although high loading conditions may be associated with lower diffuser efficiency, high loadings may not be deleterious if the loads are accounted for in design. These conditions are associated with a lower average alpha factor (the ratio of mass transfer rate in mixed liquor to the rate in clean water), which should be considered during design to avoid problems. The alpha factors observed in lightly loaded plants have

Figure 1
Ceramic Fine Bubble Dome Diffuser



Courtesy of Norton Company

Figure 2
Ceramic Fine Bubble Disk Diffuser



Courtesy of Sanitaire Water Pollution Control Corp.

been used in design of more highly loaded systems. As a result, some plants do not have enough diffusers.[4] Plant performance data from lightly loaded plants, particularly if these plants are nitrifying, should not be used to project expected performance levels for more heavily loaded plants; the converse is also true.

In general, before selecting ceramic diffusers to treat wastewaters containing high strength wastes, or process designs specifying a F/M ratio above 0.4 and a volumetric loading exceeding 50 lb BOD_5/1000 cu ft, pilot studies should be conducted to verify that diffuser sliming will not occur and/or that diffuser efficiency will not be reduced to the point where other types of aeration systems would be more cost-effective.

Aeration Tank Design

Plant survey data,[3,4] plus other studies,[6,11,12] show that ceramic fine bubble diffuser grid systems have a mixing profile that differs markedly from other types of aeration systems. This difference has a major influence on aeration tank performance and design. Dome/disk diffuser systems exhibit excellent vertical mixing but very localized horizontal flow. As a result, the extent of complete mixing in a dome/disk aeration tank is limited compared to other aeration systems. Long narrow aeration tanks with ceramic grid diffusers tend to operate as a series of zones or aeration cells, resulting in variations in both process oxygen demand and oxygen transfer efficiency along the tank.

The ratio of *actual oxygen transfer rate* (AOTR) in mixed liquor to the clean water *standard oxygen transfer rate* (SOTR) is influenced by a number of factors. These include temperature, mixed liquor dissolved oxygen levels, and other conditions measured by the *alpha factor*. Alpha provides a measure of surface active contaminants or surfactants, and varies with waste type and process conditions. Alpha can vary within the aeration tank depending on tank geometry and diffuser mixing.

For domestic wastes treated in plug flow systems, alpha values range from 0.4 to 0.8 for nitrifying processes and 0.3 to 0.7 for conventional activated sludge processes.[11] As the degree of plug flow increases in an aeration tank, the variability of alpha also increases, with minimum values generally occurring in the inlet zone of the tank. When the effects of plug flow and variability of alpha are combined, as depicted in **Figure 4**, the result is to overestimate the required air flow and number of diffusers in the inlet zone of an aeration tank. Although these effects can be counteracted by using tapered aeration, whereby more diffusers are located in the upstream grids, it becomes difficult to provide adequate tapering when an aeration tank length:width (L:W) ratio exceeds 20:1.

Plug flow can be exhibited in an aeration tank with a fine bubble diffuser system, as evidenced by distinct gradations of dissolved oxygen, in tanks with L:W ratios of less than 3.5:1 due to the diffuser mixing profile. Very pronounced dissolved oxygen gradients were observed in tanks with L:W ratios of 5:1 to 6:1. Plants with the highest oxygen transfer efficiency all had L:W ratios less than 12:1.[3,4] For new designs, a L:W ratio of 8:1 or less is recommended for conventional activated sludge systems, and a L:W ratio of 8:1 to 16:1 should be used in extended aeration (nitrifying) plants. Aeration tank L:W ratios greater than 20:1 should be avoided because physical and process

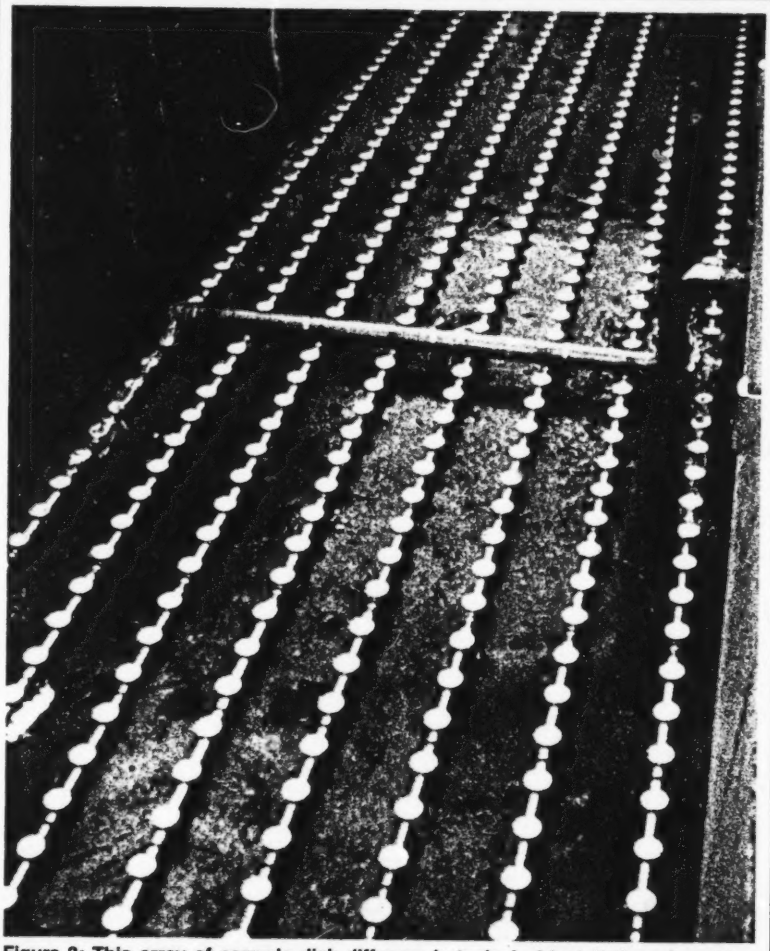


Figure 3: This array of ceramic disk diffusers is typical of installations found in activated sludge aeration tanks.

limits prevent optimal system design. When retrofitting an existing plant, the aeration tank design should be modified through inlet and outlet geometry, variation in aeration equipment, and process operation to reduce an excessive L:W ratio if possible.

The vertical mixing profile of fine bubble diffusers also promotes short circuiting in tanks that use single point feed or draw off piping or gates.[13] Multiple point inlet/outlet structures or baffles that diffuse incoming or outgoing flow across the tank, or full width weirs, can be used to avoid short circuiting.

Aeration System

The aeration system for ceramic dome/disk diffusers encompasses mixing and process air requirements, number of diffusers, diffuser air flow, diffuser distribution, mixed liquor dissolved oxygen, and the blower system, all of which affect diffuser performance.

In general, air flow requirements for mixing and biological solids suspension in fine bubble diffuser systems are less than process air requirements for most secondary activated sludge processes. Minimum air flow rates of 0.10 to 0.15 scfm per sq ft of tank floor provide adequate mixing under most process conditioning.[3,4,10] The use of conservative factors in design, particularly those derived for other types of aeration equipment, should be avoided. However, certain conditions of tank geometry, *mixed liquor suspended solids* (MLSS) concentration, and advanced wastewater treatment processes that markedly affect MLSS concentration and settleability may dictate higher mixing requirements.

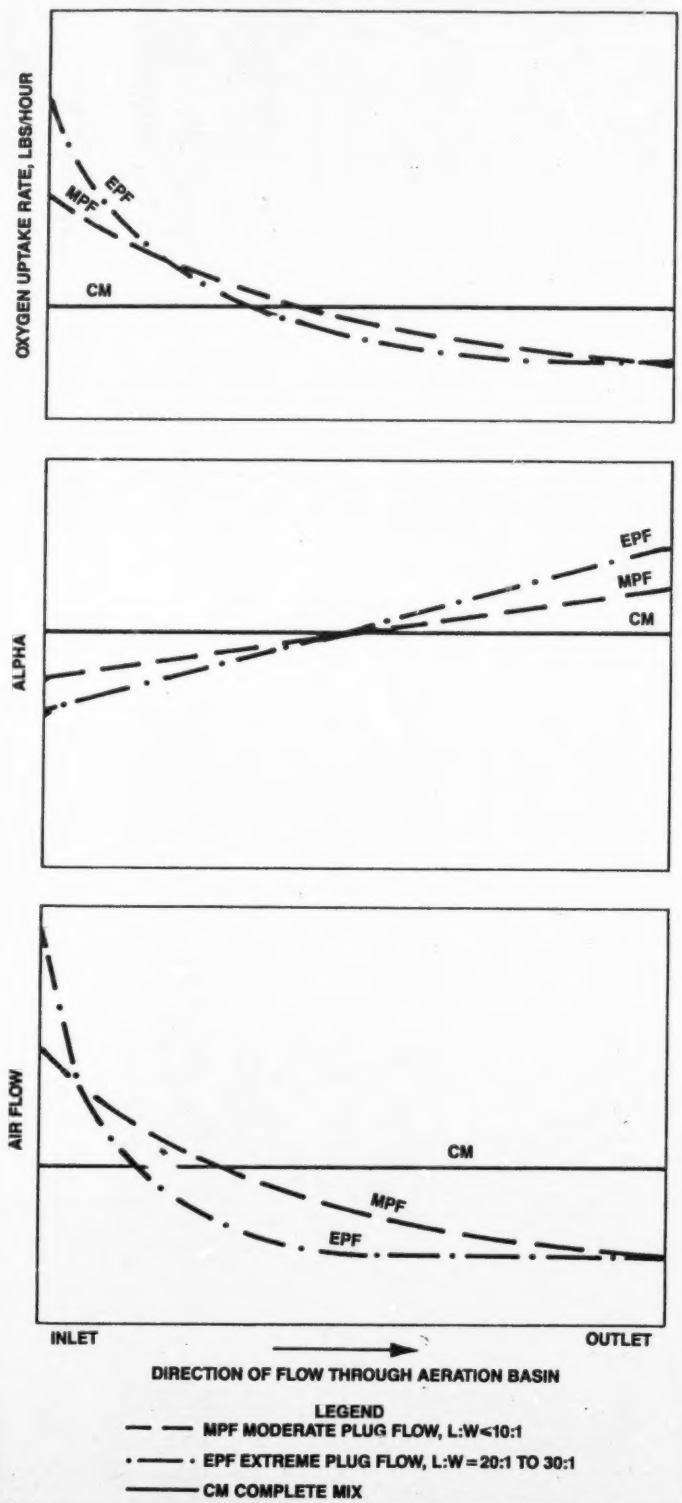
The number of diffusers needed to supply the required air flow rate is determined by the air flow rate per diffuser and system flexibility. Absolute minimum air flow rates of 0.5 cfm for 7-in. domes and 0.6 cfm for 9-in. disks are required to prevent plugging of the diffusers. Maximum air flow rates beyond 2.5 cfm for 7-in. domes and 3.0 cfm for 9-in. disks rapidly decrease diffuser efficiency due to increases in bubble size and increases in head loss. Due to minimum diffuser air flow rates, the number of diffusers in an aeration tank determines the minimum air flow to the tank. The design goal for optimal efficiency is to match the number of diffusers to the air flow requirements such that the diffusers are always operated within the range of minimum to maximum air flowrates.

The number of diffusers should be determined after considering the impact of process type, waste characteristics, and basin geometry on AOTR. A system that has too many diffusers or is greatly underloaded will be overaerated for much of the daily treatment cycle, resulting in wasted energy. Conversely, if too few diffusers and insufficient oxygen are provided, poor performance will result, diffuser fouling and associated operations and maintenance (O&M) cleaning problems will arise, and operation of the diffuser system at higher but less efficient air flowrates will be required. These effects are illustrated in **Figure 5**. A conservative estimate of the maximum number of diffusers needed should be used. To allow for error, 20 percent extra diffuser sites should be provided to facilitate the addition of extra units. A greater percentage of extra diffuser sites may be desirable in inlet zones of plug flow tanks or for more difficult applications.

The design for the diffuser system should also include a flexibility analysis as well as projections of air flow and diffuser requirements at average and peak flows. This analysis should review reqirements at minimum flows and the effects of major variations from assumed key design parameters. For example, the analysis should consider the impact on air flow and diffuser requirements for an alpha variation of ± 0.1 from the assumed value, a variation in organic loading of at least ± 20 percent, and a loss of transfer efficiency of the diffusers up to 10 percent over time as they age and become fouled. Within the limits of practicality and economics, diffuser systems should be designed to allow modifications to meet changes in operational requirements. Operational flexibility can be provided by adding extra diffuser sites and fittings on tank floor air distribution piping which allows quick installation of additional diffuser lines if needed at a later date.

The correct number of installed diffusers does not guarantee high oxy-

Figure 4
Effect of Tank Geometry on Process Oxygen Requirements, Alpha, and Air Flow Requirements



gen transfer efficiency. They must also be distributed properly in the aeration tank relative to the zones of varying oxygen demand and to offset the variable alpha effect. Tapering the diffuser grid, by decreasing the number of diffusers per unit of floor area from inlet to outlet zone of the aeration tank is the most common way to deal with this problem. Tapering is used in many plants with varying degrees of success. Presently, there is no general design methodology that guarantees correct diffuser distribution; diffuser systems are laid out using the experience and best judgment of designers and diffuser manufacturers. However, provision of extra sites for diffusers in the grid, particularly in the first third of the aeration tank or pass, will permit correction of distribution problems. In addition, plug flow aeration tanks and individual passes of step feed basins should be designed with proper L:W ratios as previously discussed to reduce the degree of required diffuser taper.

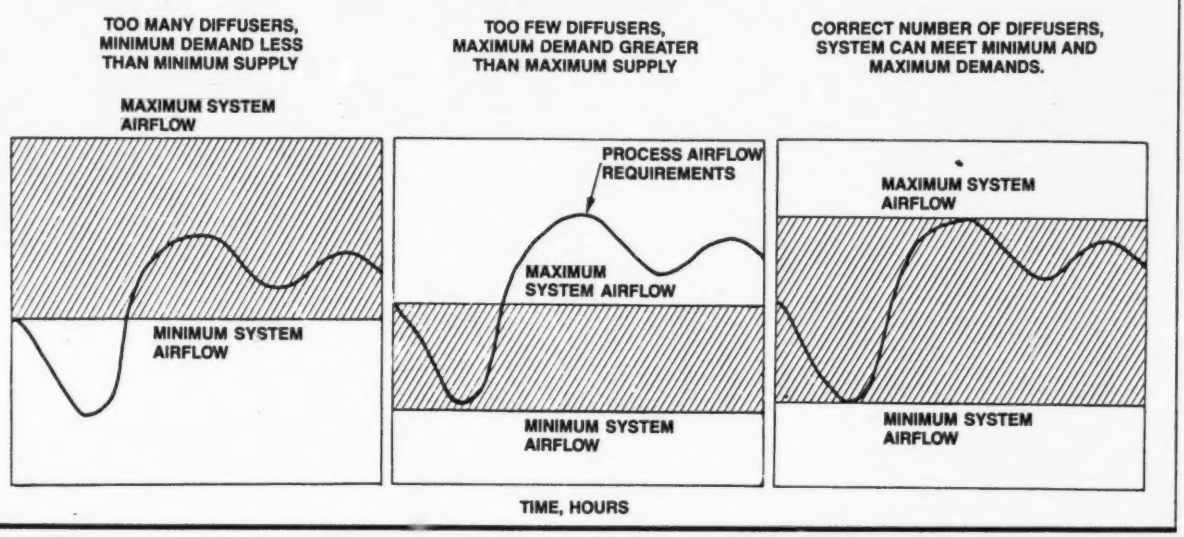
One indication of incorrect diffuser distribution is excessive dissolved oxygen in much of the aeration tank, a condition which can severely lower diffuser efficiency. In extreme cases of incorrect diffuser distribution, a definite gradient in both dissolved oxygen and slime growth, increasing from inlet to outlet zone, is exhibited. The low dissolved oxygen in the inlet zone encourages the growth of slime on the diffusers in that zone, further reducing diffuser efficiency.

Many ceramic fine bubble diffuser systems tend to operate at very high dissolved oxygen levels for much or most of the treatment day, wasting energy and, in some cases, adversely affecting the process. This problem is particularly common among new plants that are operating far below design flow. Often, plant operators are aware of this problem but can do little about it because design of the air blower system is oversized so that air flows cannot be reduced to levels required by the process. Sufficient flexibility should be provided using multiple smaller blowers, variable speed drives, or blower throttling. This will allow the blower system to be operated efficiently at start-up and during diurnal and seasonal low oxygen demand periods. Also, the blower system should be equipped with accurate instrumentation for monitoring air flow rates, blower pressure, and blower power consumption.

Equipment and Maintenance

During the first several years that dome and disk diffuser systems were

Figure 5
Number of Diffusers as a Determinant of System Efficiency


TOO MANY DIFFUSERS, MINIMUM DEMAND LESS THAN MINIMUM SUPPLY
TOO FEW DIFFUSERS, MAXIMUM DEMAND GREATER THAN MAXIMUM SUPPLY
CORRECT NUMBER OF DIFFUSERS, SYSTEM CAN MEET MINIMUM AND MAXIMUM DEMANDS.
MAXIMUM SYSTEM AIRFLOW
MINIMUM SYSTEM AIRFLOW
PROCESS AIRFLOW REQUIREMENTS
MAXIMUM SYSTEM AIRFLOW
MINIMUM SYSTEM AIRFLOW
MAXIMUM SYSTEM AIRFLOW
MINIMUM SYSTEM AIRFLOW
TIME, HOURS

installed in North American wastewater treatment plants, there were mistakes in equipment design and fabrication, as well as installation errors and oversights in O&M training. In some cases, plastic components were of incorrect formulation or inadequate thickness and strength to provide reasonable mechanical integrity. Several manufacturers experienced problems with inelastic gaskets which caused air leaks after the diffusers had been in operation for a period of time. Design and fabrication problems have been largely rectified through recent improvements in the product quality and engineering. Even so, there are still major differences among the diffuser systems marketed, particularly in the method of securing the ceramic element in place, and in the design of the joints and tank floor mounts for the grid system. Some of the hardware currently available appears better able to handle expansion and contraction, as well as installation errors. The designer should be aware of these differences as they relate to his application and specify accordingly.

Ceramic diffusers have been extensively tested under a wide variety of conditions to establish their SOTR values. If the site conditions are unique, or the diffuser manufacturer cannot provide certified test data for his diffusers tested under similar operation conditions, the specification should include clean water testing of the diffuser equipment by nationally recognized and commonly used procedures.[10] Verification of the SOTR should be required of all manufacturers of new and untested diffuser equipment which is bid as an equal to ceramic diffusers from the major manufacturers.

Equipment installation is also a concern. In a number of cases, otherwise good equipment has been damaged or improperly installed by poorly supervised contractors. Factory trained service engineers should be relied upon to provide initial training of installers and final system checkout to assure that the equipment is properly installed.

Ceramic grid diffuser systems are not and cannot be maintenance free because of the hundreds of feet of piping and thousands of pieces of hardware that can be damaged or loosened during extended periods of operation. Preventive maintenance is the key to low cost and long-term performance of ceramic grid diffuser systems. More than 20 years of experience has proven that this equipment is not unduly maintenance intensive if corrective and preventive maintenance is conscientiously applied. A principle finding has been that excellent O&M performance of ceramic dome grid diffuser systems overseas is due primarily to the knowledge and diligent care of system operators. Routine draining, tank and grid washdown, and checking every several years is standard operating procedure in virtually all plants in the U.K. Their operators have learned the signs of problems with the diffuser system and are quick to repair or change operating procedures.

The procedures for monitoring, diagnosing, and correcting problems with ceramic grid diffusers are neither time consuming nor costly. A properly trained operator can use daily visual inspection of the surface of the operating aeration tanks and periodic checking of air flow and pressure monitors to quickly and accurately assess the system's mechanical integrity and initiate any required maintenance. System performance can be tracked through mass balance measurements of system oxygen demand and measurements of air flow and power consumption. A diffuser system that has been designed with flexibility can be adjusted by adding, removing, or rearranging diffusers to tailor the system to changes in influent or process conditions.

Correctly designed and operated ceramic dome/disk diffuser systems can result in large energy savings when compared to other types of activated sludge aeration. However, some of the savings should be spent on good operator training, and thorough and periodic preventive maintenance. Operators should be provided several days of training in the monitoring, adjustment and repair of the system at start up. Also, the diffuser system design and operational principles and procedures should be detailed in the plant O&M manual.

Before he finally selects dome/disk fine bubble diffusers, the designer should carefully analyze his project to verify that it is an appropriate application of this technology. Specifically, these questions should be answered:

—Is the waste stream principally do-

mestic in origin, with typical levels of soluble BOD? If not, have pilot studies been conducted to check diffuser efficiency and propensity for slime growths?

—Is the process design loading and aeration tank geometry appropriate for dome/disk diffusers? If the process design calls for high rate treatment or high F/M loading, have pilot studies been conducted?

—If this is a new system, has the aeration tank been designed specifically for ceramic dome/disk diffusers, with appropriate tank geometry and well baffled inlets and outlets?

—If this is a retrofit of an existing aeration tank, has the tank geometry and hydraulic design been checked and modified as needed, or special provisions made in the diffuser system design to counteract poor geometry?

—Have the diffuser and air blower systems been designed with adequate flexibility to allow efficient operation at start up, as well as at fully loaded conditions? Does the design include air flow, power, and dissolved oxygen meters for monitoring and adjustment of the system in response to changing conditions?

—Is the specified diffuser hardware appropriate for the intended application? Has provision been made for expert supervision during installation and start up?

—Is the plant large enough to have or justify the instrumentation and full-time maintenance needed for satisfactory performance of a ceramic grid diffuser system?

—Will the operators be trained in diffuser operation and repair at start up? Does the O&M manual have sections on system control, problem diagnosis, and repair and performance monitoring?

—If there are major areas of concern raised by these questions, is there another type of aeration system that is less efficient but more suitable?

Typically, aeration power consumption is reduced 40 to 50 percent when converting from coarse bubble equipment to a ceramic grid diffuser system, and maintenance costs are only increased moderately if sound preventive maintenance is practiced.[3,4,12,15,16,17] However, certain minimum tank and diffuser configuration requirements must be met to obtain these savings and high organic loading rates and/or some types of industrial waste may adversely affect diffuser performance. In summary, experience shows that dome or disk ceramic grid diffuser systems can be applied successfully, and with major energy and operating cost savings, in larger treatment plants treating primarily domestic wastes. WEM

REFERENCES

1. Yunt, F. O. Present Los Angeles County Sanitation Districts' Position on the Relative Number of Diffusers Required by the Norton and Sanitaire Ceramic Fine Bubble Aeration Sytems to Achieve Equivalent Oxygen Transfer Results. Letter to J. Wren, Sanitaire Corporation (December 17, 1979.)
2. Huibregtse, G. L., T. C. Rooney, and D. C. Rasmussen. "Factors Affecting Fine Bubble Diffused Aeration." *Journal Water Pollution Control Federation* (August 1983): 1057–1064.
3. Houck, D. H., and A. G. Boon. "Survey and Evaluation of Fine Bubble Dome Diffuser Aeration Equipment." U.S. Environmental Protection Agency, EPA-600/2-81222 (September 1981).
4. Houck, D. H. "Survey and Evaluation of Fine Bubble Dome and Disk Diffuser Aeration Systems in North America." U.S. Environmental Protection Agency, pending publication.
5. Yunt, F. W., and T. O. Hancuff. "Aeration Equipment Evaluation—Phase I Clean Water Test Results." U.S. Environmental Protection Agency, Contract No. 14-12-150 (1982).
6. Boon, A. G. "The Ryemeads Experiments." Canadian Institute of Energy Seminar Paper, Toronto, Canada. (May 3, 1983).
7. U.S. Environmental Protection Agency, Wisconsin Metropolitan Sewerage District. "Investigations of Biological Fouling of Ceramic Fine Bubble Diffusers."
8. Gray Engineering Group, Inc. "Evaluation of Effects and Causes of Bio-Fouling Growth on Ceramic Fine Bubble Aeration Dome Diffusers." Research Project. (May 18, 1984).
9. Boyle, W. C., and D. T. Redmon. "Biological Fouling of Fine Bubble Diffusers: State-of-Art." *Journal of Environmental Engineering*, American Society of Civil Engineers, Environmental Engineering Division. 109–5 (October 1983).
10. Yunt, F. O., Los Angeles County Sanitation District. Memo on Results of Mixing Efficiency Tests With the Norton Dome Aeration System and the Los Angeles–Glendale Treatment Plant. (January 9, 1980).
11. Lister, A. R., and A. G. Boon. "Aeration in Deep Tanks: An Evaluation of A Fine Bubble Diffuser Air System." *Journal of The Institute of Water Pollution Control*, No. 5 (1973).
12. Boon, A. G., and B. Chambers. "Design Protocol For Aeration Systems—U.K. Perspective." British Water Research Centre, Elder Way, Stevenage (Herts), United Kingdom (1982).
13. Daigger, G., R. Marotte, and P. Kohne. "Dome Diffuser Evaluation." CH2M–Hill Engineers Internal Report (February 13, 1981).
14. U.S. Environmental Protection Agency Municipal Environmental Research Laboratory. Proceedings: Workshop Toward an Oxygen Transfer Standard. EPA 600/9-78-021 (April 1979).
15. Yunt, F. W. Personal communication with D. H. Houck regarding performance of fine bubble aerators at Whittier, California (February 1983).
16. Stenstrom, M. K., H. R. Vazirinejad, and A. S. Ng. "Economical Evaluation of Upgrading Aeration Systems." Water Pollution Control Federation Annual Conference. St. Louis, Missouri (October 7, 1982).
17. Gilbert, P. F., and J. H. Chase. "Coarse Bubble to Fine Bubble Aeration Retrofit." The Metropolitan District Commission, Hartford, Connecticut (1983).

About the Author

Daniel H. Houck, P.E., is with D. H. Houck Associates Inc. in Silver Spring, Maryland. This work was completed under a contract with the U.S. EPA. The EPA contact person is Francis L. Evans III, EPA-WERL, 26 W. St. Clair St., Cincinnati, Ohio 45268

Potassium Permanganate

DEPENDING ON ONLY ONE SOURCE

For purchasing flexibility!!

ASTURQUIMICA

The source for free-flowing grade[1]

aquox

American quality in an American-type packing from an American company[2] well stocked throughout the U.S. and ready when you need it.

In the US and Canada:
American International Chemical Inc.
(617) 655-5805
209 W. Central St. NATICK MA 01760

ASTURQUIMICA, S.A.

P.O. BOX 153 33080 Oviedo - SPAIN
Telex: 87303 nalon e

1. Meets AWWA B603-83. Technical and USP grades also available.
2. Distributed in the USA exclusively by American International Chemical Inc.

Write in 756

FIRE HYDRANT FLOW DIFFUSER

FOR UTILITY COMPANIES FLUSHING THEIR SYSTEM.

A series of interior vanes breaks up the force of the water. Hydrant can be opened without concern of injury to bystanders -- usually children playing in the water -- or damage to property. The speed of the water exiting is greatly reduced, allowing water to drop within 6 ft. of the hydrant instead of the usual 20-30 ft.

CALL OR WRITE ...

Benson Machine Works
1516 Military Avenue
Omaha, Nebraska 68111
(402) 551-5544

Write in 757